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A 13cm GaAsFET Power Amplifier Developed using the 'PUFF' CAD Software Package

Transistorised power amplifiers for the frequency range between 2,300 and 2,400 MHz have frequently been described in recent years. (1)(2)(3)(4)(5)(11)

The 2-stage power amplifier introduced here supplies an initial output of 5 Watts at 23 dB amplification in the 13cm band.

1. INTRODUCTION

The circuit was developed using the PUFF CAD software package, which makes it amazingly simple to calculate and simulate even relatively complicated microwave circuits. Several publications (7)(8), together with our own research, have already put the capability of the low-cost software used to the test, so that very positive results were to be expected.

The goal of the project was to develop several amplifiers using the software, build them, and compare the readings with the simulated values. Three different types of amplifier were involved in this project, with different performance figures varying from 4 to 12 Watts in the given frequency range.

The following article describes the selection of semi-conductors, the simulation/analysis of the amplifier circuit using the CAD software, the building of the 5 Watt amplifier and the readings obtained.

2. SELECTING SEMI-CONDUCTORS

The transistors used in the amplifier were Mitsubishi type, from the 0900 range for UHF power amplifiers. They were, in actual fact, N-channel Schottky

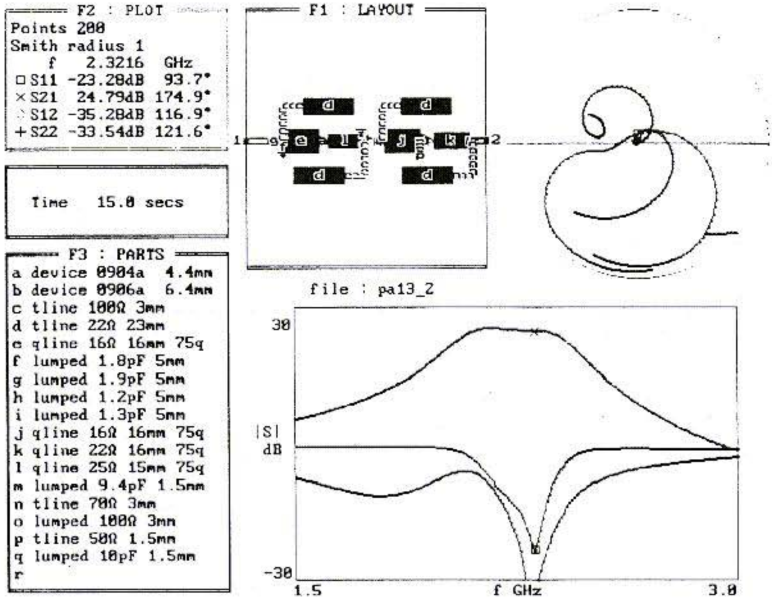


Fig.1: Screen Dump from the PUFF CAD Package

GaAs power FET's, which had already been successfully used in the construction of several circuits (6)(11), and which could be obtained at relatively low cost. Their power spectrum stretched from 0.6W (the 0904 type) right up to 10W (the 0907 type) for amplification levels of between 8 and 13dB, depending on type and frequency.

The performance figures targeted by the development:

Amplification:	> 20 dB at k > 1
Output:	min 5 W at max 1dB compression
Band width:	100 MHz

$Z_{in} = Z_{out} = 50\Omega$ at return loss ≥ 20dB

could therefore be attained only with a 2-stage amplifier.

The type 0906 seemed a suitable high-level stage transistor. It displayed particularly high operational thermal stability because of its large ceramal housing and, in contrast to the 0905, which was usually running under strain, easily supplied 37dBm = 5W at 1dB compression, thus guaranteeing stable operation with permanent output - e.g. for ATV transmitters. The type 0904 was a suitable driving transistor, because it displayed a high level of amplification (13dB) for a compression-free output amounting to almost 28dBm = 630mW. The S-parameters of the selected transistors required for the development of the circuit came from the Mitsubishi data bank, and applied under the following DC conditions:

MGF0904: UDS = 9 V at ID = 0.2 A

MGF0906: UDS = 10 V at ID = 1.1 A

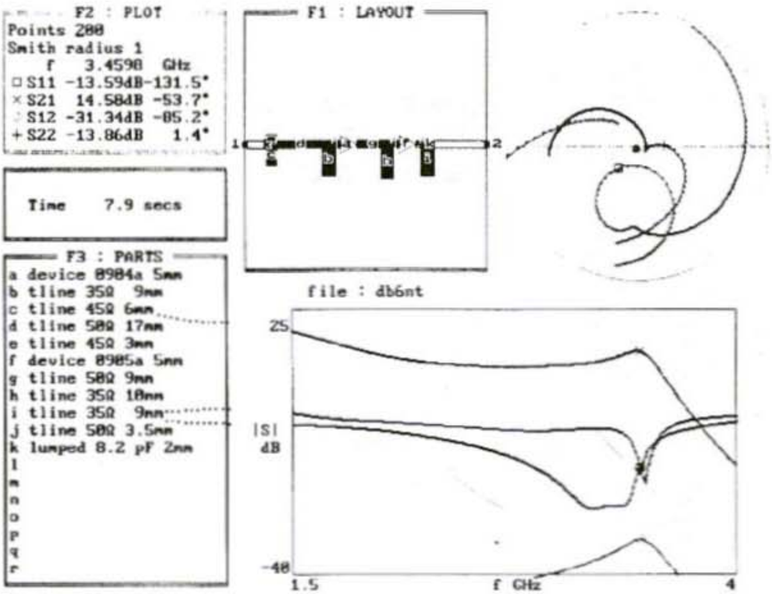


Fig.2: Frequency plots of a Circuit for the 9cm band

The efficiency of these transistors was normally about 40%, so that a DC input power of more than 12 Watts was required in operation, and the resulting power loss had to be dissipated through a heat sink of sufficiently large dimensions.

3. SIMULATION AND ANALYSIS OF AMPLIFIER CIRCUIT USING CAD SOFTWARE

The method of functioning and the operation of the PUFF CAD software are comprehensively described in (7)(8)(9), so here we shall merely list and analyse the results obtained.

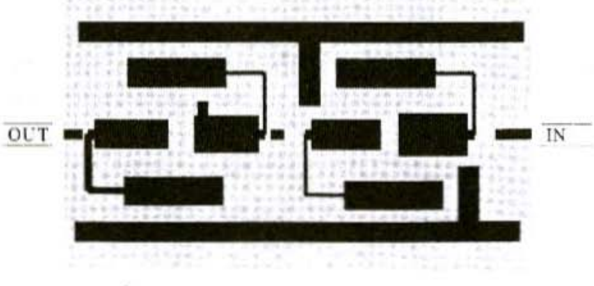


Fig.3: Board Layout generated using 'PUFF'

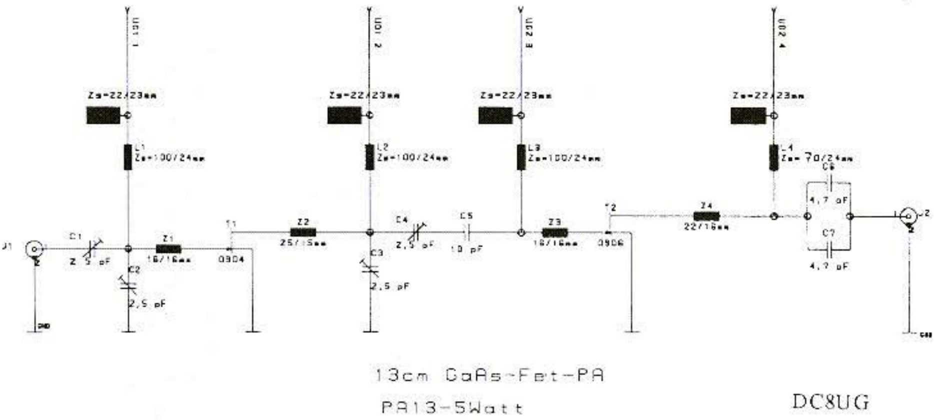


Fig.4: Circuit of the 13cm GaAsFET Power Amplifier

Fig.1 shows the screen dump from PUFF with the draft layout of the circuit, the associated Smith diagram, the parts and the paths of the scatter parameters over the frequency range selected (1.5 to 3.0 GHz). The plot window (top left) also shows the size and phase of the scatter parameters for the selected operating frequency (2.3216 GHz) in the order:

- input impedance (S11) with return loss value
- amplification (S21)
- feedback (S12)
- and output impedance (S22) with return loss value.

The stability factor of the amplification circuit at the operating frequency can be determined from the calculated scatter parameters. The theoretical relationships required for this can be found in (10). Determining the absolute stability ($K > 1$) using this factor has been tried and tested as best for normal HF amplifiers, so that from knowledge of the scatter parameters the frequency range over which the circuit will be stable can easily be indicated. A quadripole (amplifier) is absolutely stable if it always remains stable whatever the adapted load at the input and output and never self-excites.

The gain slope obtained (S21) as a function of the frequency showed a marked resemblance to that of a coupled band filter. This characteristic was obtained, firstly, through the lengthwise layout of the transmission lines (qlines/tlines) for each stage and, secondly, through the 50Ω coupling of the two stages.

With the lamina-disc method on the other hand, previously used frequently by the author for circuit matching, there is usually a gain slope like a deep pass - less reduction in amplification at low frequencies, maximum at the frequency to be transformed, and a more or less sharp reduction thereafter. This happens because the laminae, soldered on crosswise, act like stubs, which have either an inductive or a capacitive influence, depending on the frequency and length.

NAME	TYPE	VALUE	STYLE	COMMENTS
C1	TC	2.5pf	Teflon/Ceramic	Trimmer
C2	TC	2.5pf	Teflon/Ceramic	Trimmer
C3	TC	2.5pf	Teflon/Ceramic	Trimmer
C4	TC	2.5pf	Teflon/Ceramic	Trimmer
C5	C	10pf	Tekelec-Chip	Capacitor
C6	C	4.7pF	ATC-Chip	Capacitor
C7	C	4.7pF	ATC-Chip	Capacitor
J1	N			N-Connector
J2	N			N-Connector
L1	TL	Zs= 100/24mm	Stripline	Trans-Line
L2	TL	Zs= 100/24mm	Stripline	Trans-Line
L3	TL	Zs= 100/24mm	Stripline	Trans-Line
L4	TL	Zs= 70/24mm	Stripline	Trans-Line
T1	FET	0904	Mitsubishi	N-GaAsFET
T2	FET	0906	Mitsubishi	N-GaAsFET
ZS	TL	Zs= 22/23mm	Stripline	Trans-Line
Z1	TL	Z= 16/16mm	Stripline	Trans-Line
Z2	TL	Z= 25/15mm	Stripline	Trans-Line
Z3	TL	Z= 16/16mm	Stripline	Trans-Line
Z4	TL	Z= 22163mm	Stripline	Trans-Line

Fig.5: Component List for the Amplifier

To make this clearer, Fig.2 shows the simulated frequency response curve in accordance with a circuit published in (6) for the 9cm band, with 0904 and 0905 transistors, without DC choking. With slight modifications to the circuit, this amplifier can also be operated at 13cm without problems, as shown by an article in (11), though of course at considerably less than 20dB amplification.

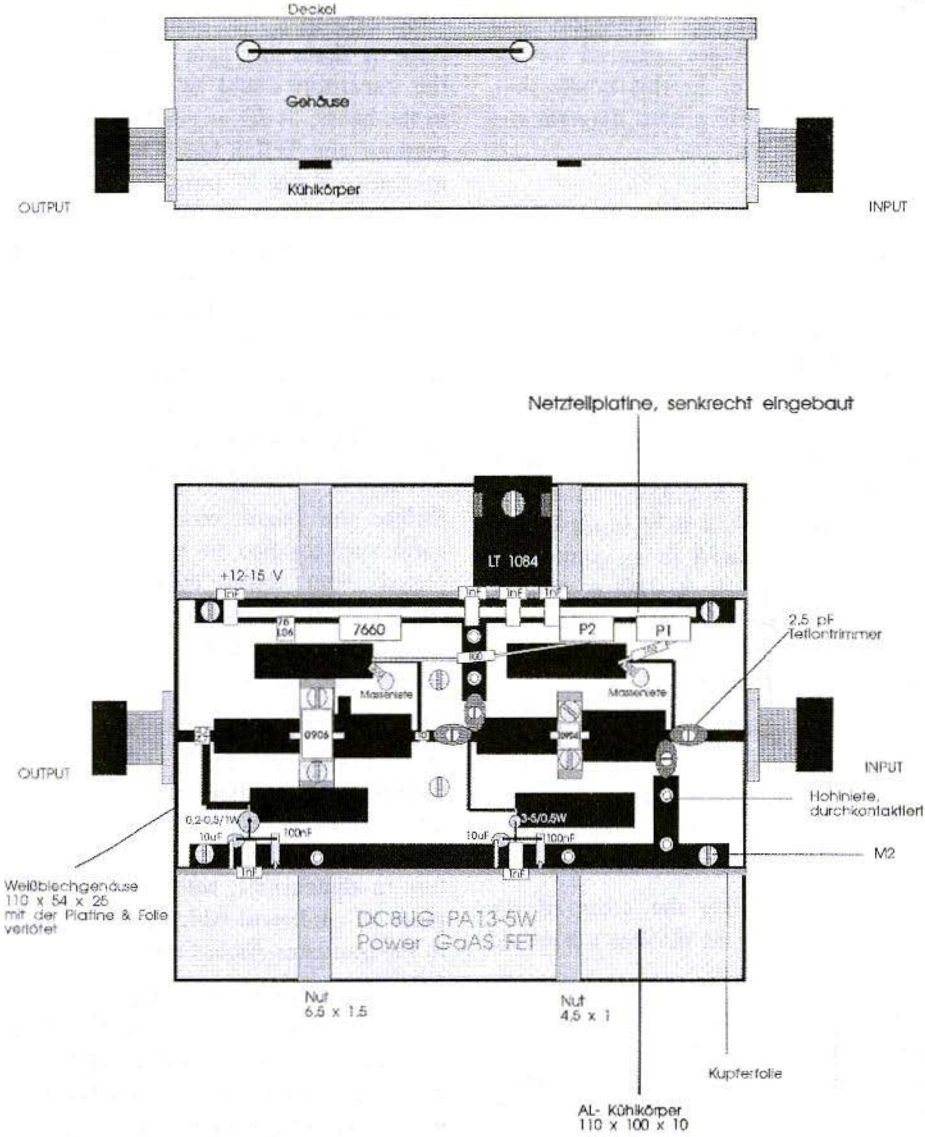
The readings shown in Fig.1 gave the following output values for the draft circuit:

- Return loss input: -23dB
- Return loss output: -33dB
- Amplification at 2,320 MHz: 24.8dB
- Feedback: -35dB
- K-factor at 2,320 MHz: 5
- Band width (-3dB): -280/+120 MHz

Fig.3 shows the layout generated by the CAD software as a print-out from a laser printer for Teflon-based material with a substrate thickness of 0.79mm. The subsequent introduction of a correction factor to generate a precise photographic model is thus possible. The reversed image is pictured, as generated on the exposed board.

The tracks on the longitudinal board side are earth surfaces inserted subsequently, which are through-hole plated to the earth surface when the circuit is assembled.

In the parts list in Fig.1, we can also recognise the discrete modules required for the circuit under the description of



Fig's.6a& b: Side view of mechanical structure and the Component Placement and Assembly plan
(Deckel = cover; Genhäuse = housing; Kühlkörper = heatsink Netztellplatine, senkrecht wingebaut = PSU board, vertically mounted; Weißlechhgehäuse = tinplate housing; mit der platine & folie verlötet = soldered to board and foil; Nut = slot; Hohlniete durchkontakiert = hollow rivet, through-hole plated; AL - Kühlkörper = Al heatsink; Kupferfolie = copper foil

"lumped". These are capacitors and resistances which are required for the circuit to operate. In this connection, Fig.4 shows the HF circuit diagram and Fig.5 the parts list.

4. ASSEMBLING THE AMPLIFIER

The amplifier circuit was built on a Teflon board (er = 2.33) with dimensions of 109 x 54 x 0.79 (mm) For its part, it was screwed to an aluminium cooling body (110 x 100 x 10mm), which was used for fastening and as a heat sink for the power transistors and voltage controllers (Fig.6).

The use of epoxy resin based material was excluded, since power amplifiers in this range already produce dielectric losses of 20% (app. 1dB), i.e. a loss of 1W at 5 Watts output.

So, compared with the costs of the transistors (app. DM 60/Watt), it would be a false economy.

The DC power supply system was assembled on an epoxy board, coated on both sides (91 x 20 x 1.6mm), which was vertically soldered to the longitudinal side of the housing (Fig.6) within. Its circuit corresponded to the one published in (6).

Figs. 7, 8 and 9 show the screen, layout and parts list for this power supply. The components are mounted on the foil side, so that the earth surfaces have to be through-hole plated.

Grooves were milled in the heat sink so that the drain and gate connections of the transistors could be soldered flush to the board, as far as possible. For this purpose, the Teflon board had recesses measuring 4.4 x 17 (mm) and 6.4 x 22 (mm), into which the transistors were inserted and then screwed to the heat sink (see Fig.6). There was also a copper foil between the board and the heat sink (115 x 57 x 0.08mm), which was later soldered to the tinplate housing. It provided a very good earth connection between the transistors, the board, the housing and the heat sink.

Before the board was mounted, the earth surfaces had to be through-hole plated with 2mm copper (hollow) rivets. At least 4 rivets per longitudinal side and earth connector are required for this (see Fig.6).

The board was fastened to the heat sink at 6 points, using M2 screws. The transistors each required 2 threaded holes in the baseplate for the source connection, which were best provided, true to dimensions, with the help of a piece of cardboard which corresponded to the transistor dimensions.

The dimensions of the tinplate housing were 110 x 55 x 28 (mm) and before assembly it was provided with the necessary bores for the feedthrough capacitors and recesses for the N-sockets. The housing itself was then soldered together, and soldered to the longitudinal sides of the screwed-on board. The soldered-on sockets could then be screwed to the heat sinks on the front faces as well.

The best insertion and commissioning procedure is as follows:

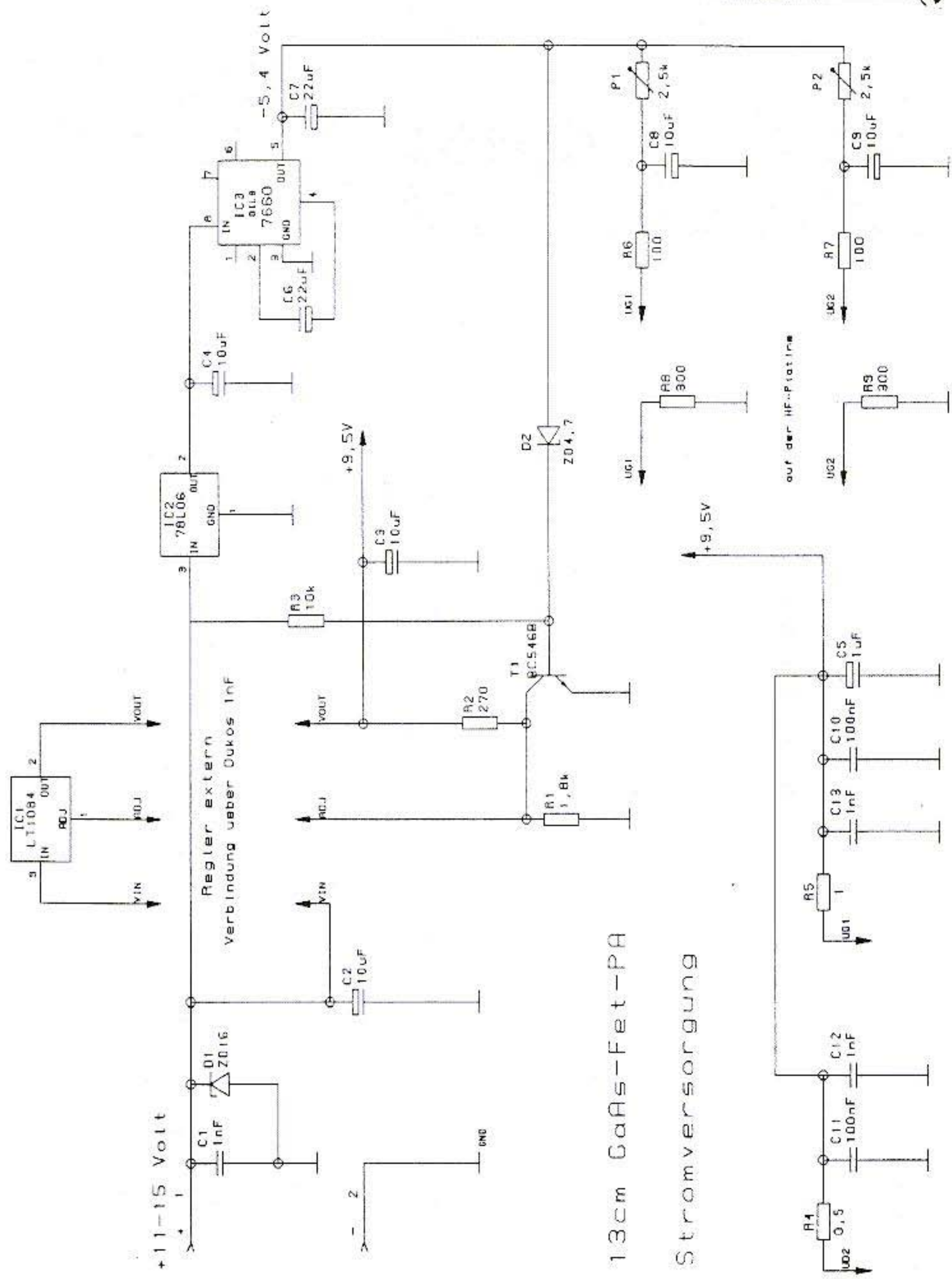


Fig.7: PSU Circuit
(Stromversorgung = power supply; Regler extern,Verbindung ueber Dukos 1nf = external regulator, connection through 1nF feedthrough capacitors; auf der HF-platine = on the HF board

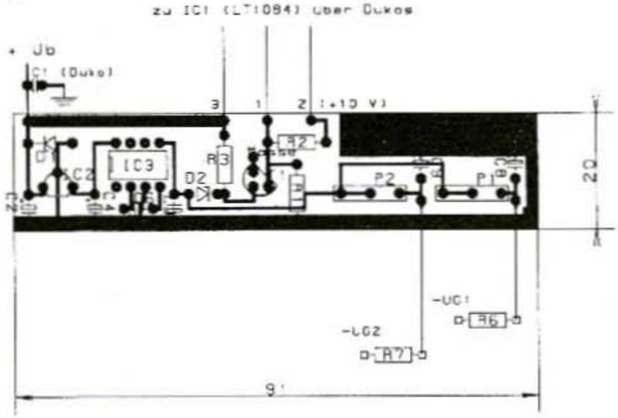


Fig.8: Layout and Component Overlay for the PSU (Dukos = feedthrough capacitor)

NAME	TYPE	VALUE	STYLE	COMMENTS
C1	C	1nF	Feedthrough	Capacitor
C2	EC	10uF	Tant/16V	Electrolytic
C3	EC	10uF	Tant/16V	Electrolytic
C4	EC	10uF	Tant/16V	Electrolytic
C5	EC	1uF	Tant/16V	Electrolytic
C6	EC	22uF	Tant/10V	Electrolytic
C7	EC	22uF	Tant/10V	Electrolytic
C8	EC	10uF	Tant/10V	Electrolytic
C9	EC	10uF	Tant/10V	Electrolytic
C10	C	100nF	Sibatit	Capacitor
C11	C	100nF	Sibatit	Capacitor
C12	C	1nF	Feedthrough	Capacitor
C13	C	1nF	Feedthrough	Capacitor
D1	Z	ZD16	Zener Diode	
D2	Z	ZD4.7	Zener Diode	
IC1	LT1084		TO247	Low drop reg
IC2	78L06		TO92	+ve Regulator
IC3	ICL7660		DIL8	-ve Regulator
P1	P	2.5k (2k)	Piher/Cermet	Potentiometer
P2	P	2.5k (2k)	Piher/Cermet	Potentiometer
R1	R	2k (22k ll 2.2k)	Metal film	Res, 2.2 x 6.3mm
R2	R	270	Metal film	Res, 2.2 x 6.3mm
R3	R	10k	Metal film	Res, 2.2 x 6.3mm
R4	R	0.2 - 0.5 /1W	Metal film	Res, 2.2 x 6.3mm
R5	R	3 - 5 /0.5W	Metal film	Res, 2.2 x 6.3mm
R6	R	100	Metal film	Res, 2.2 x 6.3mm
R7	R	100	Metal film	Res, 2.2 x 6.3mm
R8	R	300	Metal film	Res, 2.2 x 6.3mm
R9	R	300	Metal film	Res, 2.2 x 6.3mm
T1	NPN	BC546B	SOT54	NPN Transistor

Fig.9: PSU Component List

- Assemble and mount power supply board
- Gate resistances (R6, R7) should already be soldered onto power supply for better mounting (see Fig.8)!
- Assemble and wire up the 6 feedthrough capacitors (1nF) and the blocking capacitors C3, C5, C10, C11
- Fasten (insulation!) and connect up voltage controller by means of feedthrough capacitors
- Mount and connect up resistances (R4, R5, R8, R9) to and on HF board
- Mount trimmers (C1, C2, C3, C4)
- Mount chip capacitors (C5, C6, C7)
- The power supply (UG and D) can now be tested.
- Mount GaAsFET's

The static current levels can now be set:

0904 - ID = 0.2A; 0906 - ID = 1.1A

Note: for continuous operation in unfavourable conditions, it is advisable to mount the amplifier on an additional heat sink (e.g. the housing wall), to ensure stable operation.

5. READINGS

The prototype amplifier was constructed so that a 5 Watt output could be achieved with an input of 28mW at 2,320 MHz. The measurement was carried out using a type HP 432 Wattmeter and a 30dB attenuator from Narda.

Fig.10 shows the transfer characteristic of the amplifier.

At 5 Watts output, the compression range begins, i.e. a further increase in power leads to a considerable worsening of the inter-modulation interval; (1dB compression $\cong$ -33dB$_{in}$).

Fig.11 shows the power amplification at an input 10mW over the frequency range.

Curve A shows the measured gradient arising if the amplifier is tuned to 2,320 MHz.

Curve B shows the gradient obtained through simulation, in accordance with Fig.1.

Consequently, the amplifier has a band width of 300 MHz. Its amplification reduction at the band limits is of course somewhat less than in curve B. The reasons for this are the losses conditional on the circuit, which can not be covered completely by the simulation.

The linear amplification of 2dB obtained is only slightly different from the calculated value. If the amplifier is broad-band tuned, so that its course corresponds to curve B, the amplification falls by about 1dB (20%) as the band width increases.

To sum up, we can say that using PUFF low-cost software to develop simple integrated high-frequency circuits can be highly recommended. True, the efficiency is very much reduced by comparison with high-end products such as, for example, Super-Compact, but the results obtainable are more than adequate for the amateur sector.

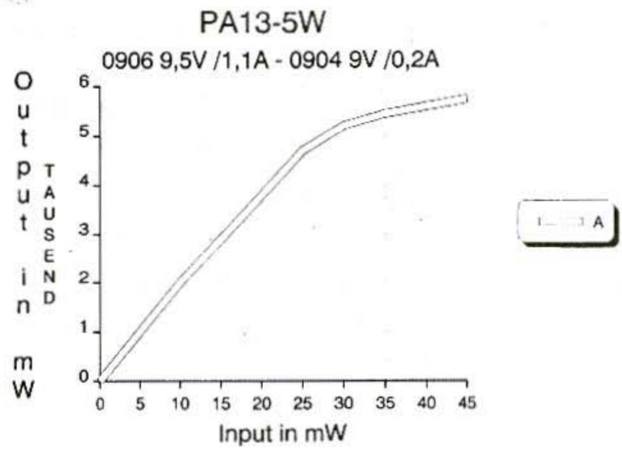


Fig.10: Transfer Characteristics of the Amplifier Tausend = thousand)

6. LITERATURE

(1) Heidemann, R: Linear 1 Watt Amplifier for the 13cm Band VHF Communications 4/81 pp. 204 - 206

(2) Senkel, H.J.:13cm Transceiver Dubus-Info, no. 3, 1982, pp. 169 - 170

(3) Fleckner, H.: 13cm Power Amplifier Dubus-Info, no. 3, 1982, p. 170

(4) Nele, C.: 7W Transistorized 13cm Linear Amplifier Dubus-Info, no. 1, 1984, pp. 3 - 7

(5) Fleckner, H. & Himmler, K.: 13cm Pre-Amplifier and 13cm (2W) PA Dubus-Info, no. 2, 1986, pp. 149 - 154

(6) Kuhne, M.: High-Power GaAsFET Amplifier for 9cm. Dubus-Info, vol. 20 (1991), no. 2, pp. 7 - 16

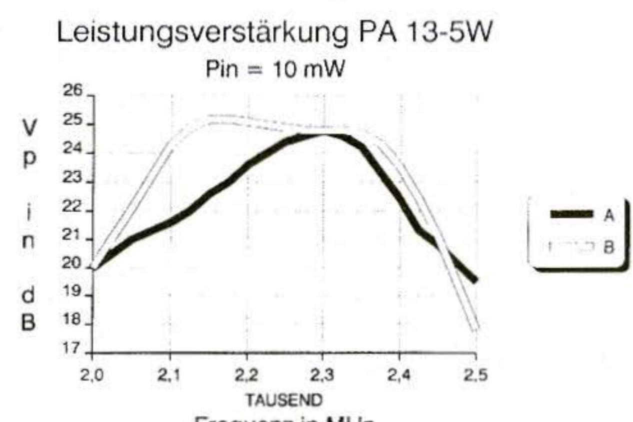


Fig.11: Comparison of Measured and Simulated Power Amplification (Leistun gsverstärkung)

(7) Bertelsmeier, R.: PUFF Design Software
Dubus-Info, vol. 18 (1989), no. 4, pp. 30 - 33

(8) Lentz, R.E.:PUFF - CAD Software for Microwave-Stripline Circuits
VHF Communications, 2/91, p. 66

(9) Wedge, S.W., Compton, R. & Rutledge, D.:PUFF Computer Aided Design for Microwave Integrated Circuits
Puff Distribution, California Institute of Technology, Pasadena

(10) Unger/Harth:High-Frequency Semi-Conductor Electronics
Hirzel-Verlag, Stuttgart
ISBN 37776 02353

(11) Schmitt, G.:13cm Power Amplifier with GaAs
Dubus-Info, vol. 20 (1991), no. 4, pp. 55 - 56

***Note**: The PUFF software package is available from KM Publications. Please see our software catalogue on the rear cover of this issue.*